Technical Report No. 177

SACLANT ASW
RESEARCH CENTRE

# THE RELATIONSHIP BETWEEN THOSE PHYSICAL PROPERTIES OF UNDERWATER SEDIMENTS THAT AFFECT BOTTOM REFLECTION

by

TUNCAY AKAL

15 OCTOBER 1970

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# THE RELATIONSHIP BETWEEN THOSE PHYSICAL PROPERTIES OF UNDERWATER SEDIMENTS THAT AFFECT BOTTOM REFLECTION

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## ABSTRACT

Over the last few years very many cores have been taken from various parts of the ocean bottom, ranging from harbours to abyssal plains. This study presents the relationship between those physical properties of the sediments that affect bottom reflection, by using the data from more than 400 cores taken from various physiographic regions of the Pacific and Atlantic Oceans and the Norwegian, Mediterranean and Black Seas. The compressional sound velocities and densities measured in the cores and the Rayleigh reflection coefficients computed from these values are discussed with respect to their dependence on porosity. It is found that density and reflection coefficients can be related to porosity by a simple linear equation, and sound velocity by a second-order polynomial equation.

## INTRODUCTION

The bottom of the ocean is covered by sediments with different physical properties, and a knowledge of these properties is essential for the understanding of reflection and refraction of sound from this environment.

The main purpose of this work is to use available marine-sediment data to obtain a better understanding of the relationship between those physical properties of bottom sediments that affect bottom reflection. These data were obtained from 456 cores taken from various physiographic regions of the Pacific and Atlantic Oceans, and the Norwegian, Mediterranean and Black Seas (Refs. 1 to 24).

Compressional velocity, bulk density, and porosity of the marine sediments are the most important physical properties that determine the acoustical nature of the bottom, and these properties have received considerable attention in works already published (Refs. 6, 7, 9, 10, 14, 15). Many theoretical equations (in which mathematical models are employed with certain assumptions) and statistical equations (in which the measured values of these properties are used by applying statistical methods) have been developed by these authors and tested to some extent with the limited data.

Because of the difficulties of measuring many properties of the marine sediments that are necessary for the theoretical equations, only the statistical methods have been used here.

# 1. THE PHYSICAL PROPERTIES OF THE BOTTOM SEDIMENTS RELATED TO BOTTOM REFLECTION

Reflection occurs whenever a wave strikes the interface marking the change in physical properties between two media. The amount of energy reflected, and its phase relative to the incident wave, depend on the ratios between the physical properties on opposite sides of the interface.

## 1.1 Reflection Coefficient

For transmission between two fluid media [Fig. 1], such as across the water/sediment interface, when there is no damping, the reflection coefficient, which was originally worked out by Rayleigh [Ref. 26], is given by

$$R = \frac{\frac{\rho_2}{\rho_1}\sin\theta - \sqrt{\left(\frac{c_1^2}{c_2^2}\right) - \cos^2\theta}}{\frac{\rho_2}{\rho_1}\sin\theta + \sqrt{\left(\frac{c_1^2}{c_2^2}\right) - \cos^2\theta}} \qquad \text{[Eq. 1]}$$

where $\theta$ is the grazing angle, $\rho_1$ and $c_1$ are the density and the sound velocity of water, and $\rho_2$ and $c_2$ are the density and the sound velocity of the sedimentary layer respectively.

If the relative density $\rho = \rho_2/\rho_1$ and the relative sound velocity $\alpha = c_2/c_1$ are used to present the contrast between the two media Eq. 1 becomes

$$R = \frac{\rho\sin\theta - \sqrt{\frac{1}{\alpha^2} - \cos^2\theta}}{\rho\sin\theta + \sqrt{\frac{1}{\alpha^2} - \cos^2\theta}} \qquad \text{[Eq. 2]}$$

and, for an incident path normal to a reflecting horizon, i.e. $\theta = 90°$,

$$R = \frac{\rho\alpha - 1}{\rho\alpha + 1} \qquad \text{[Eq. 3]}$$

## 1.2 Critical Angle

When the velocity of sound is greater in the second medium ($\alpha > 1$), as the grazing angle is decreased a unique value is reached at which the angle of refraction becomes 90°. This is known as the critical angle and is given by

$$\theta_{cr} = \arccos (1/\alpha) \qquad \text{[Eq. 4]}$$

When the grazing angle is less than this critical angle, all the incident acoustic energy is reflected. However, the phase of the reflected wave is then shifted relative to the phase of the incident wave by an angle varying from 0° to 180° and is given as

$$\Phi = -2 \arctan \sqrt{\frac{\cos^2 \theta - 1/\alpha^2}{\rho \sin \theta}} \qquad \text{[Eq. 5]}$$

## 1.3 Angle of Intromission

In the oceans generally the sound velocity in the top layer of the bottom is less than in the water above ($\alpha < 1$); as will be shown in Chapter 4 this occurred in 89% of the samples studied. In such conditions there is an angle of intromission at which most of the incident energy is transmitted into the sedimentary layer and the reflection coefficient becomes zero for

$$\cos \theta_I = \sqrt{\frac{\rho^2 - 1/\alpha^2}{\rho^2 - 1}} \qquad \text{[Eq. 6]}$$

The phase shift is 0° when the grazing angle is greater than the intromission angle and 180° when it is smaller than the intromission angle.

As can be seen in Eqs. 2, 3, 4, 5 and 6, such acoustical characteristics of the bottom as the critical angle, the angle of intromission, the phase shift, and the reflection coefficient, are primarily influenced by the relative density and relative sound velocity of the environment as a function of the grazing angle.

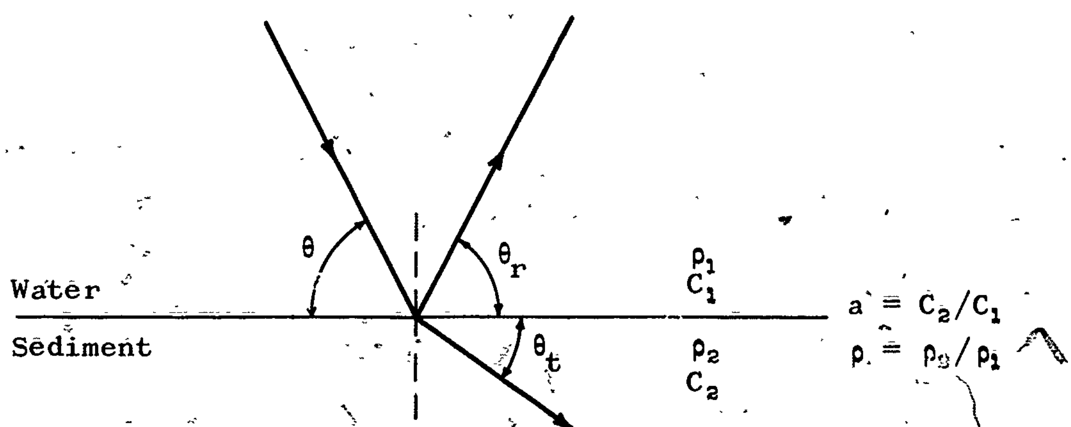



FIG. 1 GEOMETRY AND NOTATIONS

## 2. COMPILATION OF MEASURED DATA

### 2.1 Sources

Core data from the North Atlantic Ocean, the Norwegian Sea, the Mediterranean Sea, and the Black Sea were found in Refs. 1 to 14.

#### 2.1.1 North Atlantic Ocean and Norwegian Sea

Figure 2 shows the major physiographic regions of the North Atlantic Ocean and Norwegian Sea, together with the approximate positions of the cores. The work of Heezen et al (Ref. 16) is here updated with the data obtained from recent surveys (Refs. 1, 2, 17, 21, 23) and its limit extended from latitude 50°N to 70°N.

The percentage distribution of the major physiographic regions in the area is shown in Fig. 3. It is seen that 41.7% of the area consists of continental rises, basins and abyssal plains, and, as shown in the lower part of the figure, 67,4% of the cores were taken from these regions.

#### 2.1.2 Mediterranean and Black Seas

Figure 4 shows the physiographic regions of the Mediterranean and Black Seas, together with the positions of the cores. This map is based on Ref. 1 and Refs. 18 to 25 and is updated with unpublished SACLANTCEN data. The Black Sea section of the map has been constructed from the bathymetric profiles of Ref. 18.

The percentage distribution of the major physiographic regions in the Mediterranean and Black Seas is shown in Fig. 5. As can be seen, most of the cores (52.1%) were taken from basins and abyssal plains, which cover only 23.1% of the Mediterranean and Black Seas.

## 2.2 Method

From 456 available cores, 15124 samples for the density/porosity relationship and 8287 samples for the sound-velocity/porosity relationship were obtained and transferred to the computer for statistical analysis, computation and plotting.

To be able to handle this large quantity of data taken from various regions by different methods and analysed in different conditions with different methods, all bulk density and compressional sound velocity data were transferred into relative density and relative velocity with respect to the bottom water values.

The samples used to obtain the relationships are not only from the water/sediment interface. As can be seen from Fig. 6, 50% of the cores are more than 6 m long and 12% are more than 10 m long, the relationships obtained from these samples are valid for at least 10 m into the sea bottom.

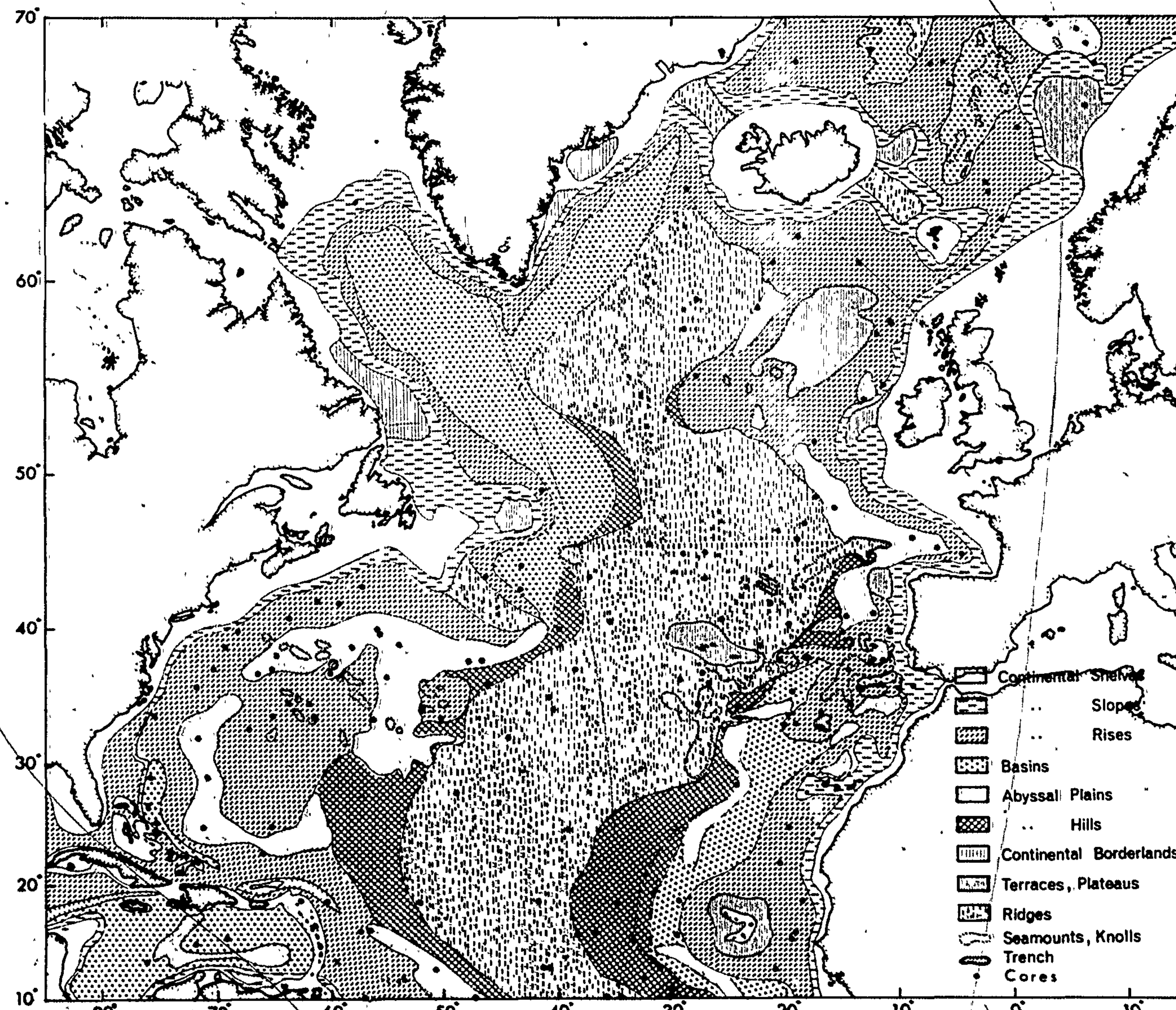



FIG. 2 MAJOR PHYSIOGRAPHIC REGIONS OF THE NORTH ATLANTIC OCEAN AND THE NORWEGIAN SEA, showing positions of data cores

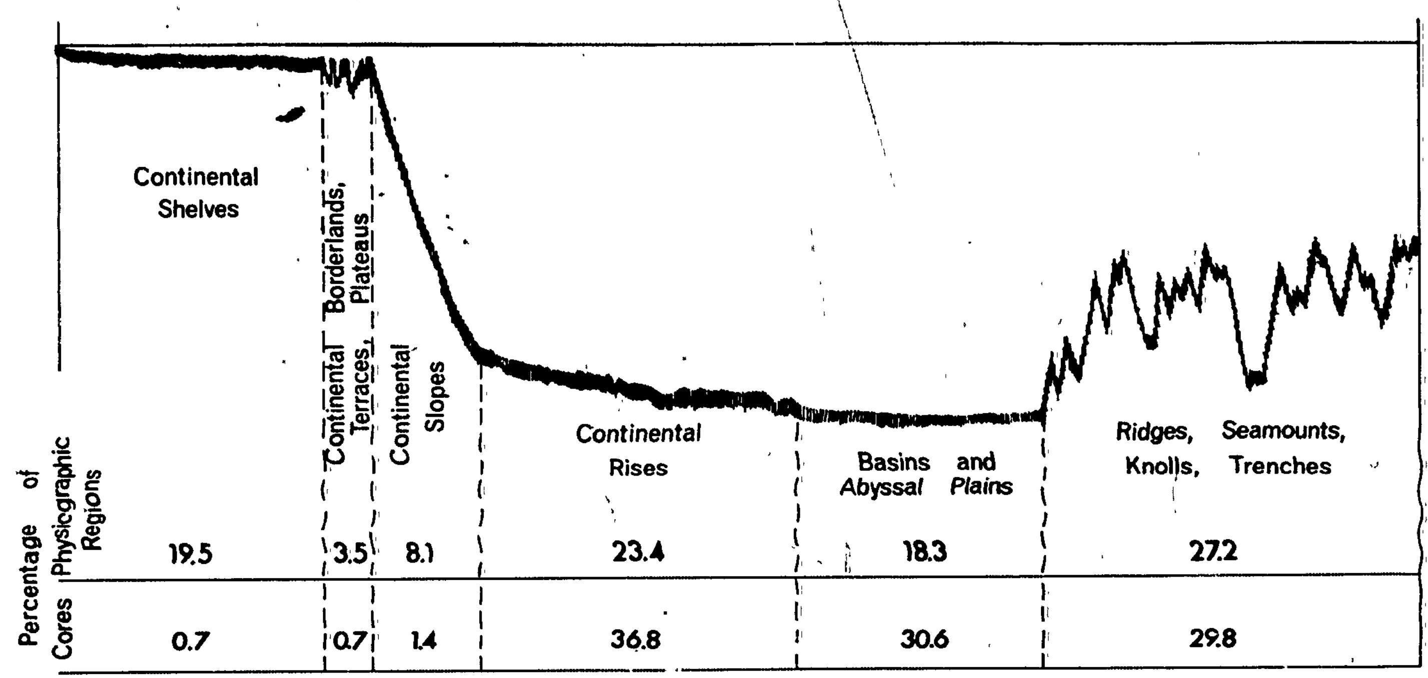



FIG. 3 PERCENTAGE DISTRIBUTION OF THE MAJOR PHYSIOGRAPHIC REGIONS AND OF THE DATA CORES IN THE NORTH ATLANTIC OCEAN AND NORWEGIAN SEA

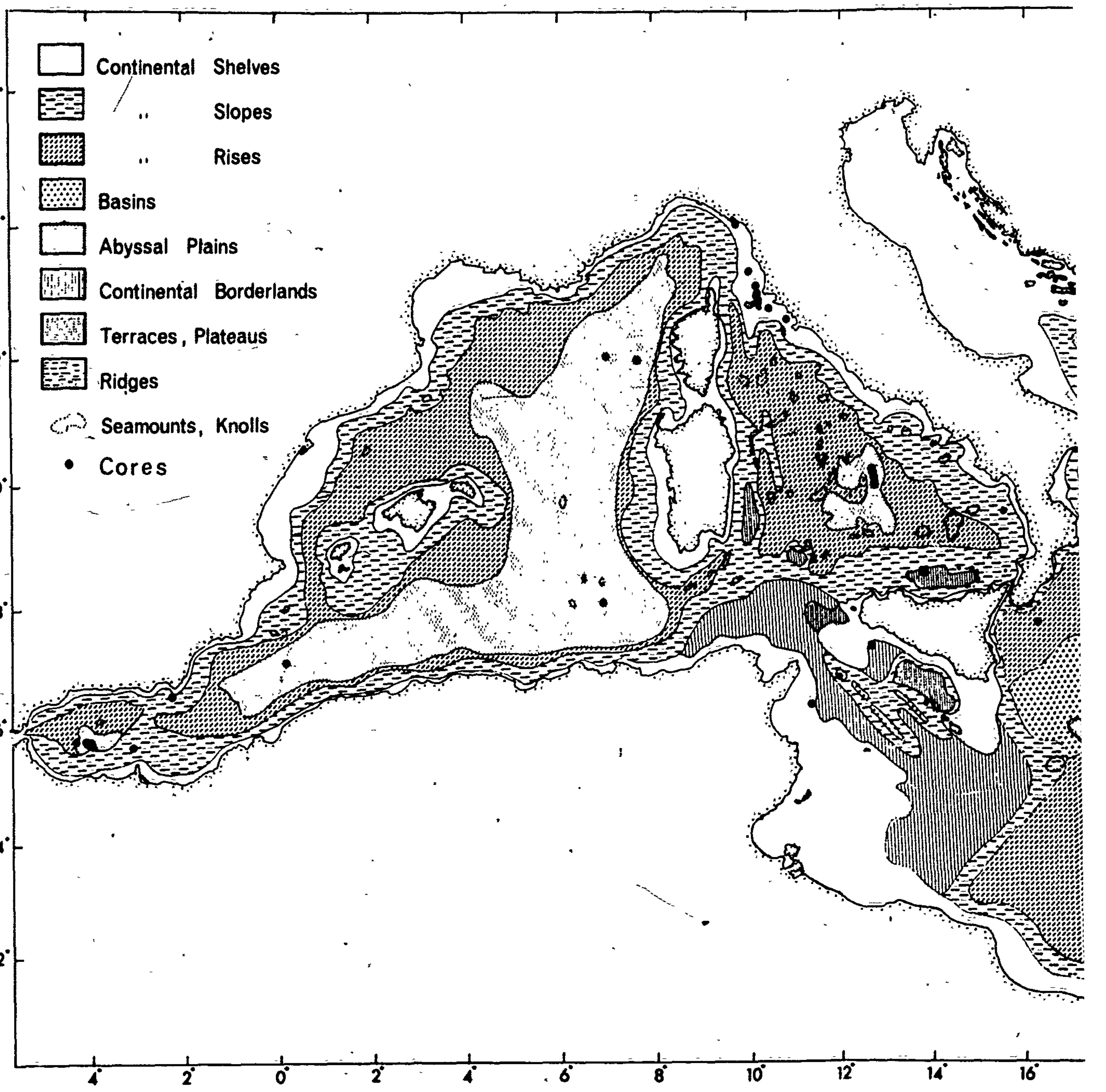
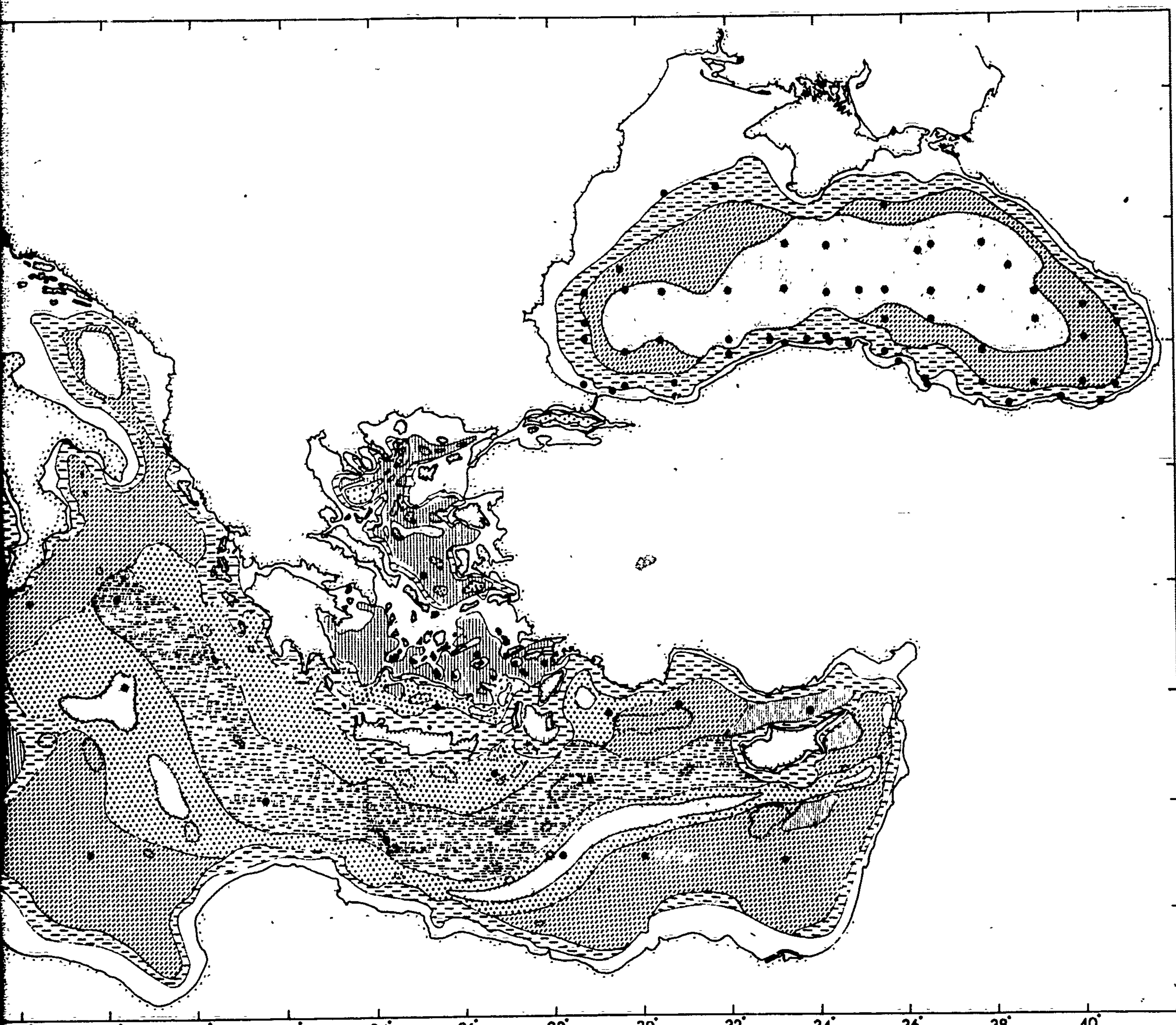



FIG. 4 MAJOR PHYSIOGRAPHIC REGIONS OF THE MED




HE MEDITERRANEAN AND BLACK SEAS, showing positions of data cores

2

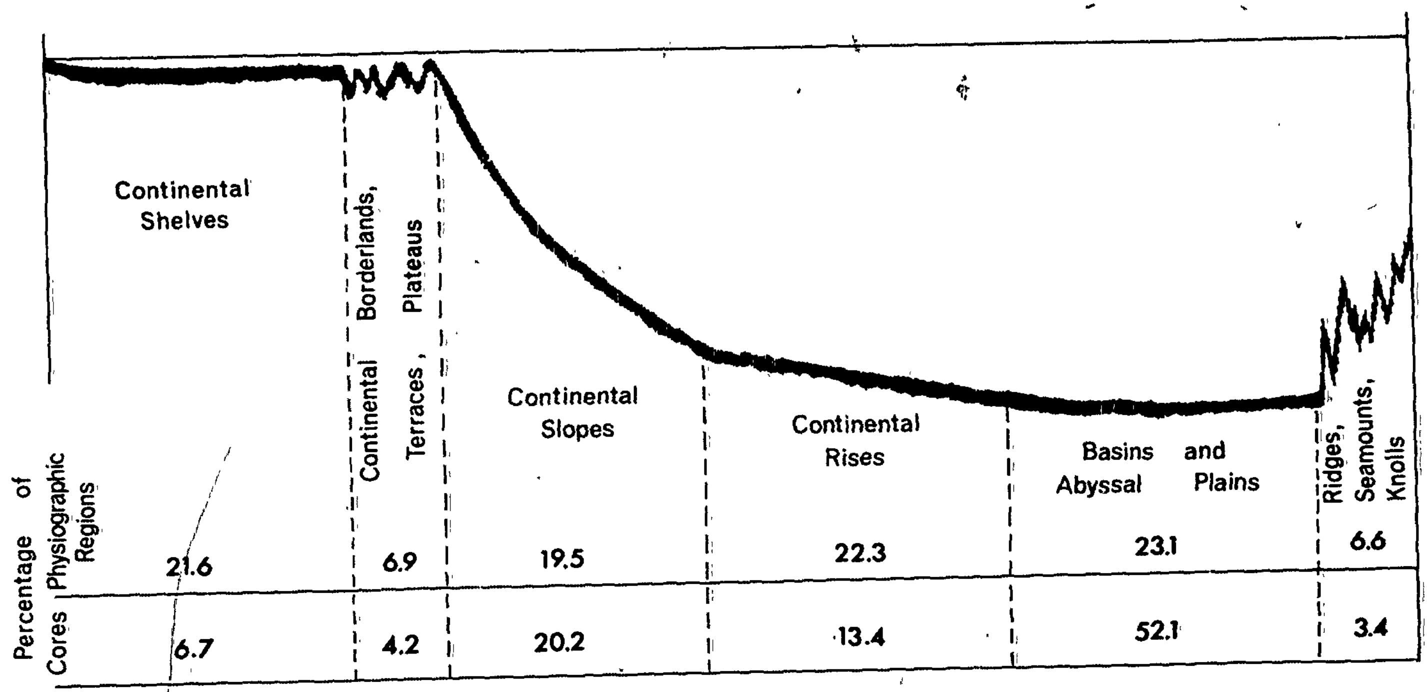



FIG. 5 PERCENTAGE DISTRIBUTION OF THE MAJOR PHYSIOGRAPHIC REGIONS AND OF THE DATA CORES IN THE MEDITERRANEAN AND BLACK SEAS

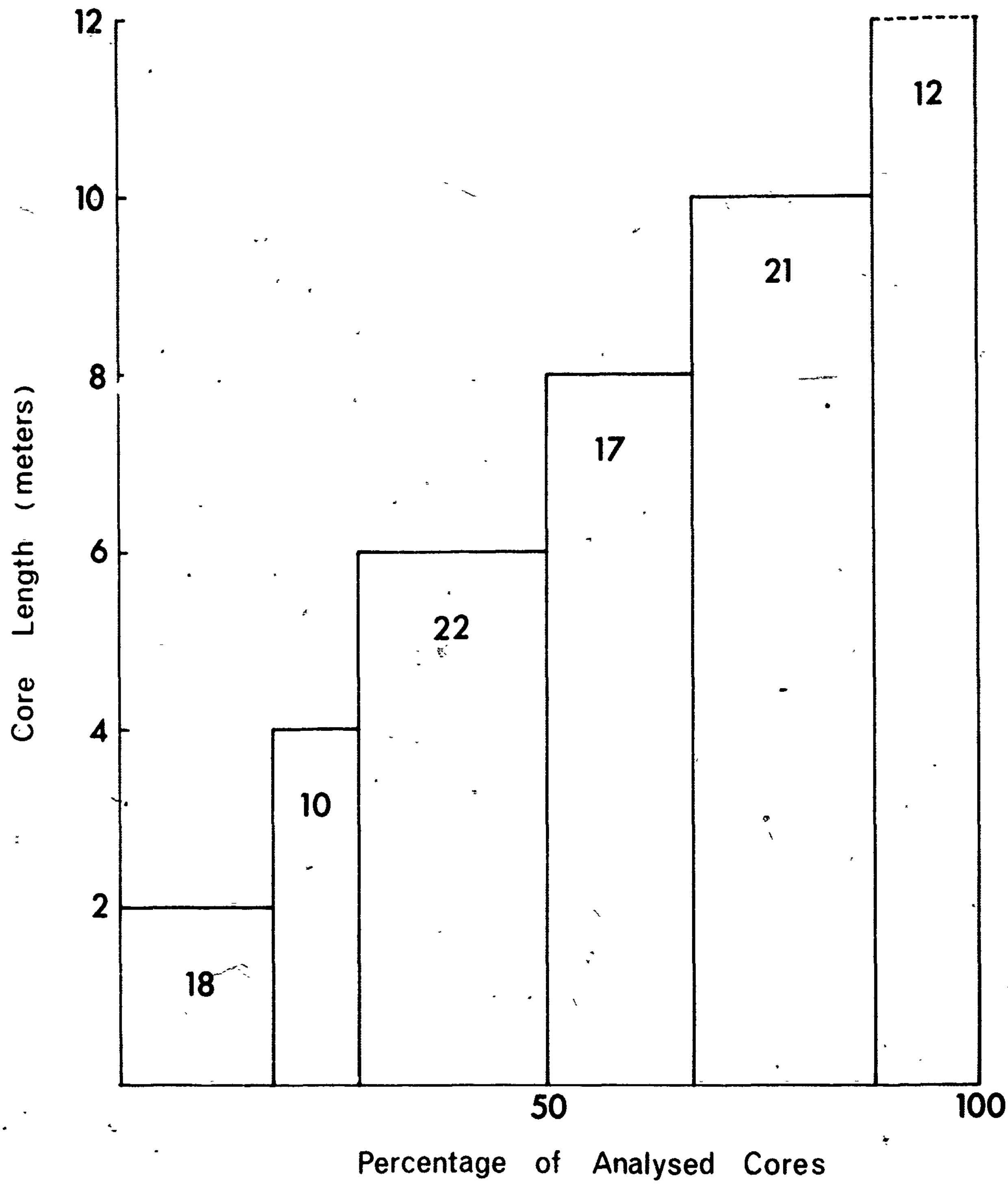



FIG. 6 LENGTHS OF ANALYSED CORES

## 3. THE RELATIONSHIP BETWEEN MEASURED PHYSICAL PROPERTIES

### 3.1 Porosity and Relative Density

A marine sediment may be defined as a deposit of different mineral particles whose pore space is filled by sea water. Its porosity is given by the percentage volume of the porous space and its bulk density by the weight of the sample per unit volume.

The relationship of porosity to bulk density has already been investigated by some authors (Refs. 6, 7, 9, 10, 14, 15) with fewer data and shown to have a strong linear correlation.

Theoretically this linearity only exists if the dry densities of the mineral particles are the same for all marine sediments. The density of the sediment would then be the same as the density of the solid material at zero porosity, and the same as the density of the water at 100% porosity. If this relationship is expressed by linear interpolation for the intermediate values, the equation is given as

$$\rho_2 = P\rho_1 + [1 - P]\,\rho_d \quad , \qquad \text{[Eq. 7]}$$

where $\rho_2$ = the density of the sediment,

$\rho_1$ = the water density,

$\rho_d$ = the dry density of the mineral particles,

$P$ = the porosity of the sediment.

To check this linearity for measured values, the relative density ($\rho_2/\rho_1$) has been plotted as a function of porosity for the 15124 available samples and a regression line fitted by computer. As can

be observed from Fig. 7, the points come very close to fitting a single straight line given by

$$\rho = 2.6 - 1.6\ P \quad , \qquad \text{[Eq. 8]}$$

where, as before, $\rho$ is the relative wet density and P is the porosity.

If this relationship is applied to Eq. 7, the density of the solid particles ($\rho_d$) in the marine sediments is given as 2.66. As shown in Fig. 7, the measured data fall mostly between the lines representing dry densities of 2.60 and 2.75. Since this difference is very small, the relative wet density of the marine sediment can be calculated from the porosity by using Eq. 8.

3.2 Porosity and Relative Sound Velocity

Considered as a propagation medium, marine sediments consist of two basic components: the solid particles and the water-filled porous spaces. When the compressional seismic wave propagates in a marine sediment the velocity of this wave is determined by the elastic properties of the sediment.

Many authors have proposed equations for the prediction of compressional wave velocities provided some of the environmental properties are known. Certain of these equations, which are particularly related to this study, are briefly described below.

A.B. Wood [Ref. 28] assumed that, in the mixture, the acoustic pressure acting on a mineral particle is the same as that in a homogenous fluid in the same position (the particles are moving in phase with the fluid), and that the bulk modulus and the shear modulus of the particles are negligible. The velocity of compressional waves is expressed as

$$\alpha = \sqrt{\frac{1}{\beta_2\,\rho_2}} \qquad \text{[Eq. 9]}$$

where $\beta_2$ is the compressibility of the sediment. For a suspension

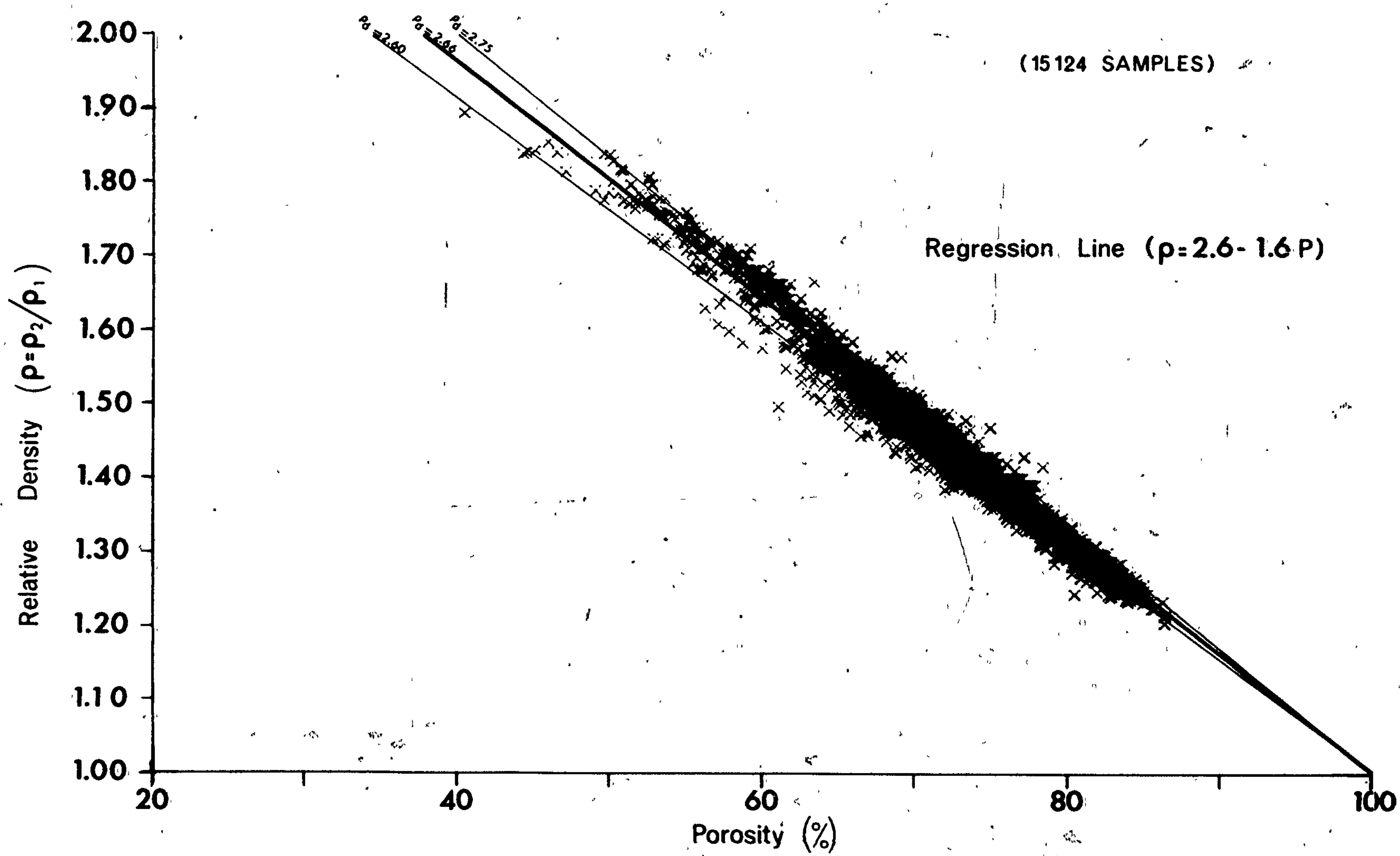



FIG. 7 RELATIONSHIP BETWEEN RELATIVE DENSITY AND POROSITY

of solid particles in water Wood considers the bulk compressibility to be equal to the sum of the compressibilities of the individual particles multiplied by their proportion of the total volume, and expressed in the following form:

$$\beta_2 = P\beta_1 + (1 - P)\ \beta_d \quad , \qquad \text{[Eq. 10]}$$

where $\beta_1$ = the compressibility of water,

$\beta_d$ = the compressibility of the mineral particles in the sediment,

$P$ = the porosity.

A corresponding relation also holds for bulk density, which is expressed as Eq. 7.

Urick [Ref. 29] applied Wood's equation to the case of dilute suspensions and obtained an agreement between the theoretical and experimental results.

Nafe and Drake [Ref. 15] also showed that Eq. 9 gave reasonable agreement with the available experimental results for the variation of compressional wave velocities with the porosity of the sediment.

Shumway [Ref. 30] showed that because rigidity was neglected Wood's equation has limitations, especially on low porosities, and he introduced a small rigidity modulus and a constant to give a best-fit curve to the data. The compressional wave velocity is expressed in the following form:

$$\alpha_{Shumway} = \sqrt{(K_2 + b\ (1 - P)\ \Psi/\rho_2)} \quad , \qquad \text{[Eq. 11]}$$

where $b$ is a constant (0.8, chosen by Shumway),

$K_2$ is the bulk modulus of the sediment,

$\Psi$ is the particle concentration of particles with a diameter greater than 62.5 microns, where the given values of $\Psi$ are 1.0 at $P = 0.40$, 0.3 at $P = 0.525$ and zero at $P = 0.80$.

Similar empirical modifications have been introduced by Nafe and Drake [Ref. 15], and Wyllie et al [Ref. 31] to obtain better agreement between the experimental and theoretical results; all these studies dealt with the parameters that are difficult to measure, i.e. bulk modulus, shear modulus.

To check how the compressional wave velocities vary with the porosity of the marine sediments, data from 8287 samples have been plotted in Fig. 8 to show this relationship. The curves obtained from Wood's and Shumway's equations are plotted in the same figure, together with the curve which is given as

$$\alpha = 1.631 - 1.78\ P + 1.2\ P^2 \qquad \text{[Eq. 12]}$$

The curve was fitted by the least-squares technique, employing the whole of the data and using a computer. As can be seen from this figure, the relative velocities range from 1.30 to 0.95, and porosity ranges from 0.25 to 0.90. The difference between Wood's curve and Shumway's curve is significantly high in the porosities below 0.45, owing to the neglect of rigidity in Wood's equation.

Figure 9 shows the locations and the number of samples for this relationship. As can be seen, the sound velocity in 89% of the samples was less than that in water and 83% of these had porosities between 60% and 82%. Figure 10 also shows the same relationship in three-dimensional form. It is recalled that, as seen in Figs. 2 and 4, 66% of the cores used in this study were taken from continental rises, basins and abyssal plains, where the sediment particles mainly consist of fine-grained clay minerals.

## 3.3 Porosity and Reflection Coefficients

The reflection coefficient of the upper layer is dependent on the product of the density, the sound velocity and the angle of the incident wave; the reflection coefficient for normal incidence (90° grazing angle) at a single interface has been computed from

relative density and relative sound velocity data and plotted against porosity in Fig. 11. As can be seen, there is a strong linear correlation, expressed by the regression equation

$$R = 0.589 - 0.59\,P \qquad \text{[Eq. 13]}$$

The reflection coefficient for the first interface can usually be measured directly as the ratio between the first peak amplitudes of the direct and the reflected signals. If the reflection loss at normal incidence is known, it will be possible to predict the other parameters by using the statistical relationships between the physical properties of the sediment.

The relationships of relative sound velocity with the Rayleigh reflection coefficient, the porosity, and the relative density, obtained from the statistical analysis of the data are shown in Fig. 12.

Figure 13 shows the measured and computed reflection losses at different grazing angles [Ref. 31]. Measured reflection losses at normal incidence have been employed to predict the relative density and relative sound velocity of the upper layer and these data have been used to compute (without taking account of damping or shear waves) the reflection losses at oblique angles. The zone covered by the curves which are obtained from this computation is diagonally hatched in the same figure. As can be seen, the reflection loss curves obtained from normal incidence measurements show a good agreement with measured reflection losses and with those computed from the core data (by taking the damping into account), except near the angle of intromission where the effect of damping is noticeable.

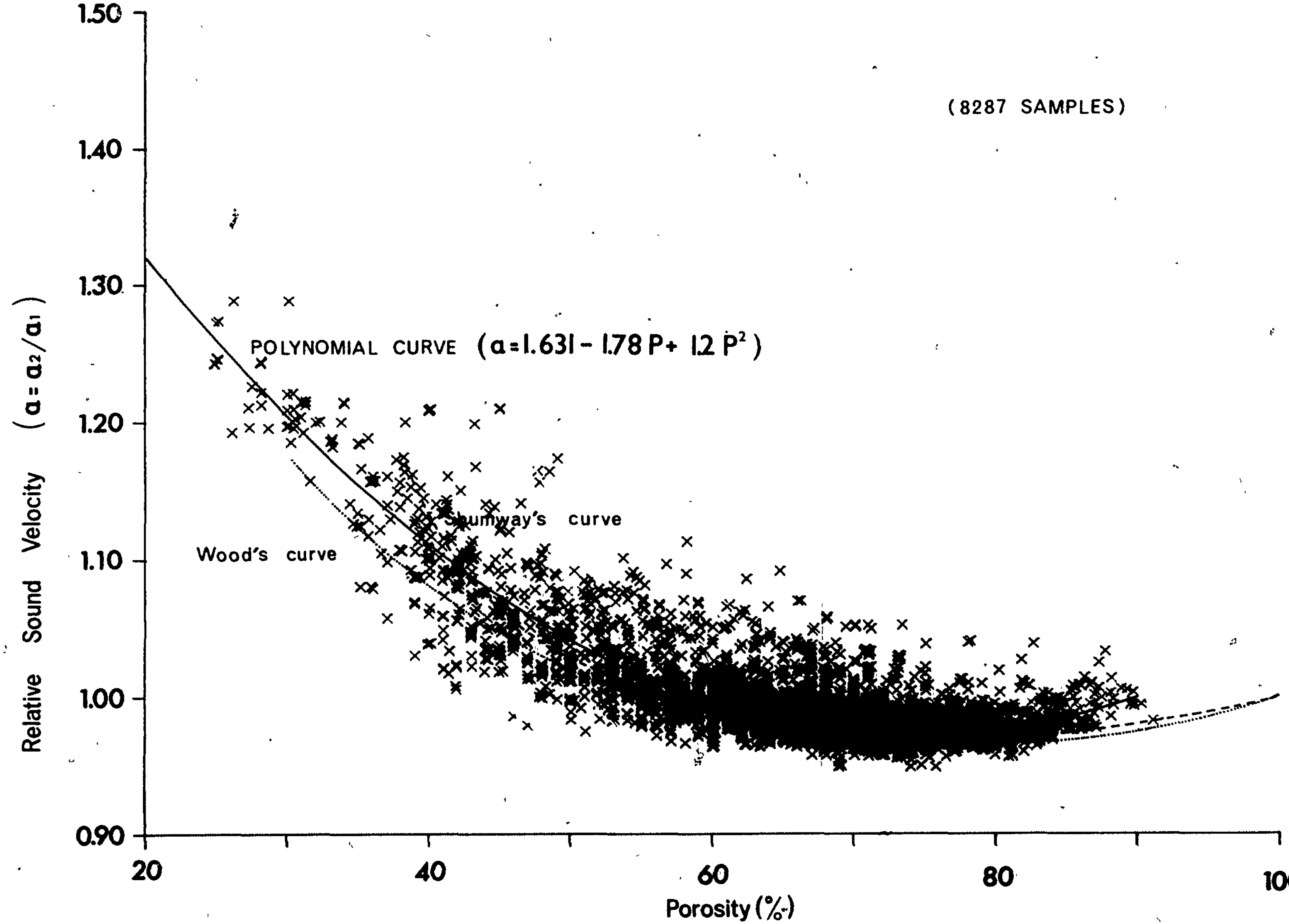



FIG. 8 RELATIONSHIP BETWEEN RELATIVE SOUND-VELOCITY AND POROSITY

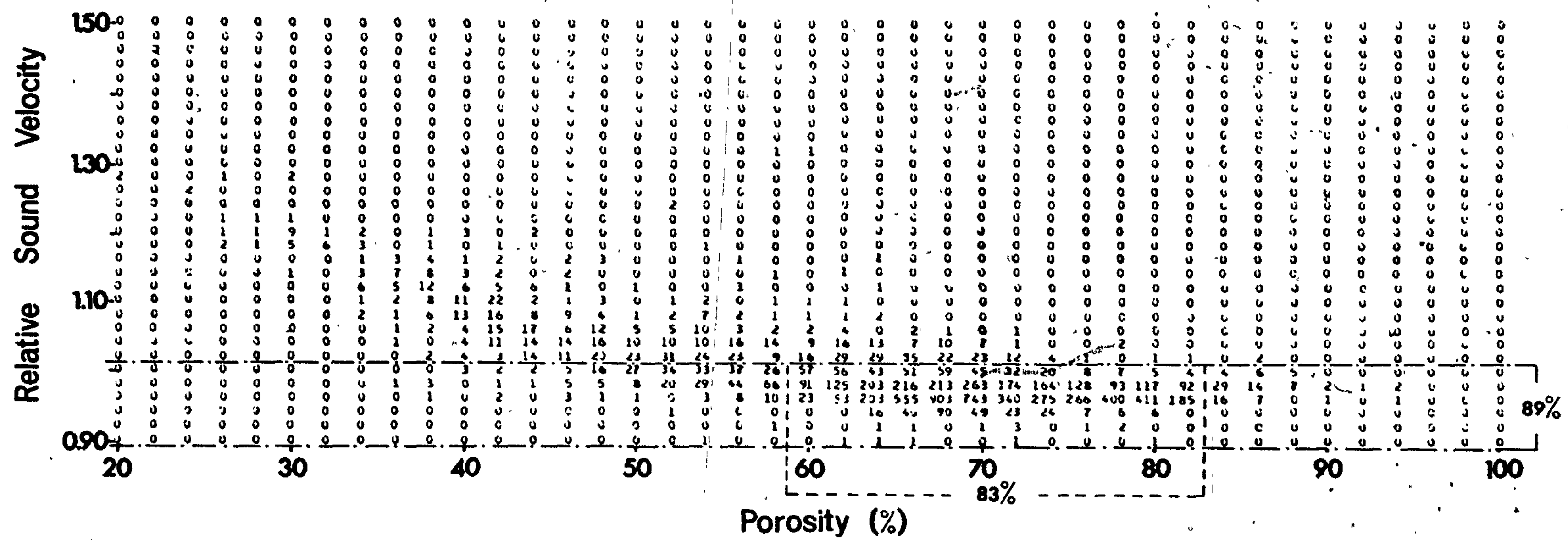



FIG. 9 LOCATIONS AND NUMBERS OF SAMPLES USED FOR ESTABLISHING RELATIONSHIP BETWEEN RELATIVE SOUND-VELOCITY AND POROSITY

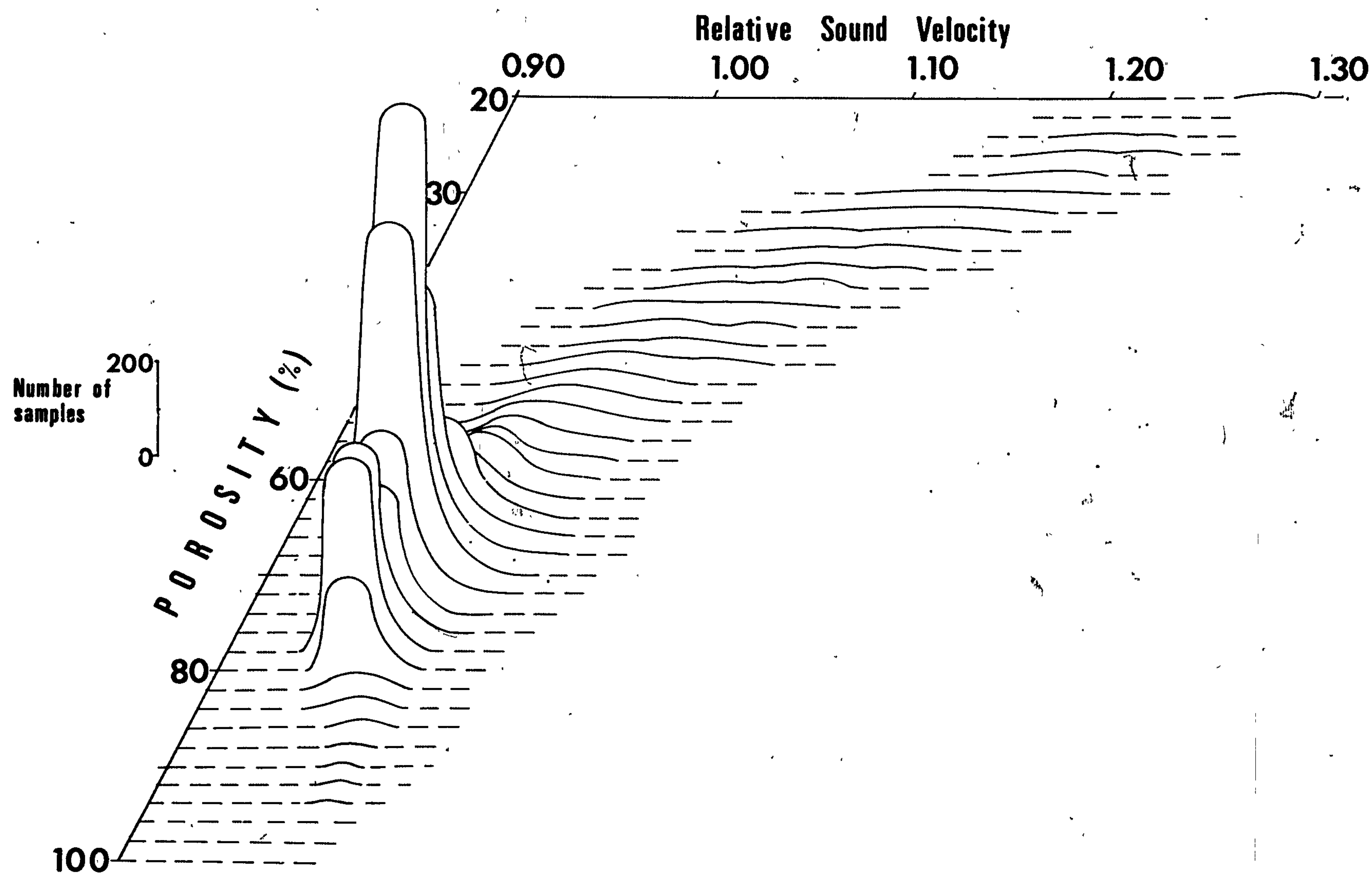



FIG. 10 THREE-DIMENSIONAL REPRESENTATION OF THE RELATIONSHIP BETWEEN RELATIVE SOUND-VELOCITY AND POROSITY

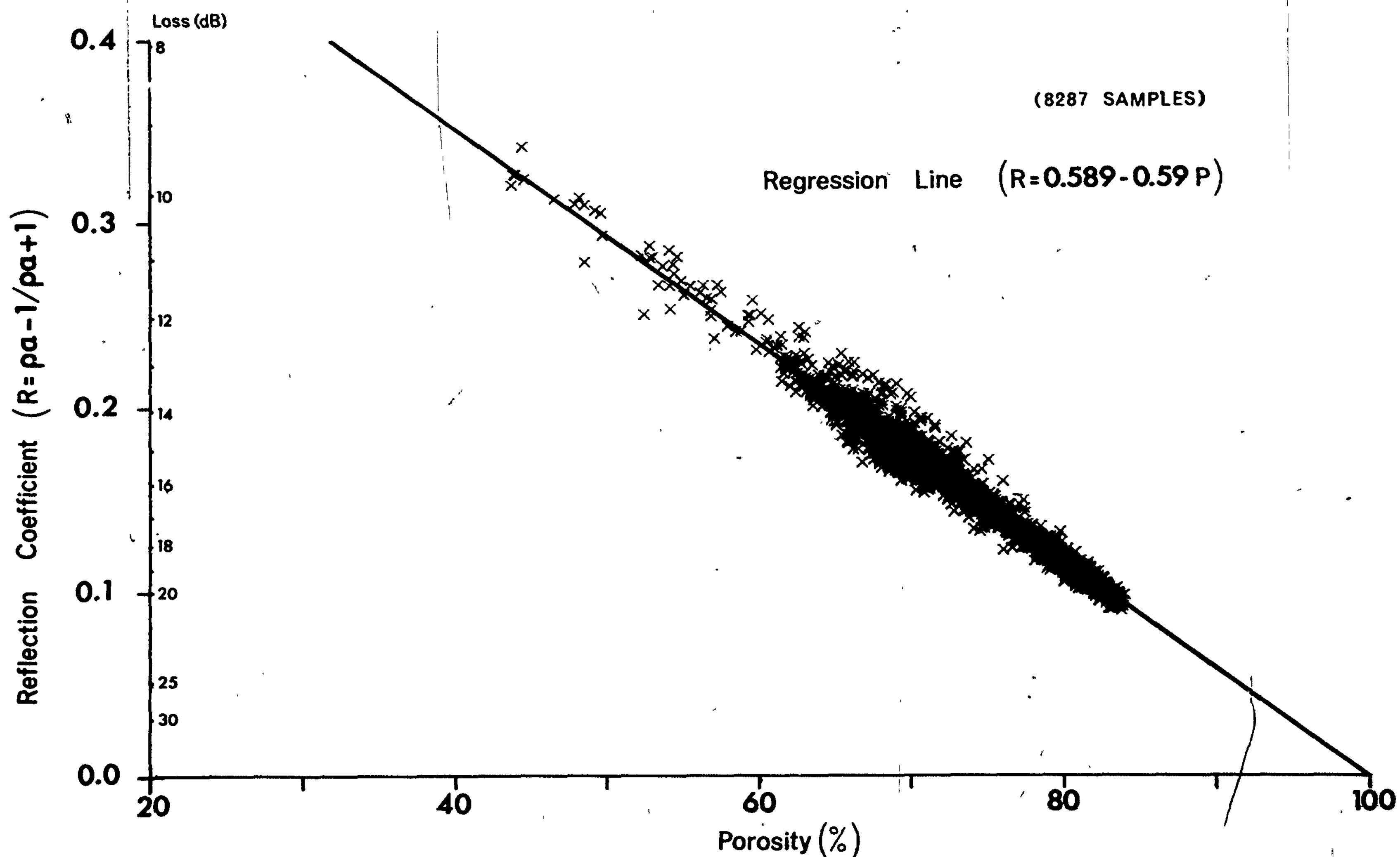



FIG. 11 RELATIONSHIP BETWEEN THE REFLECTION COEFFICIENT AND POROSITY

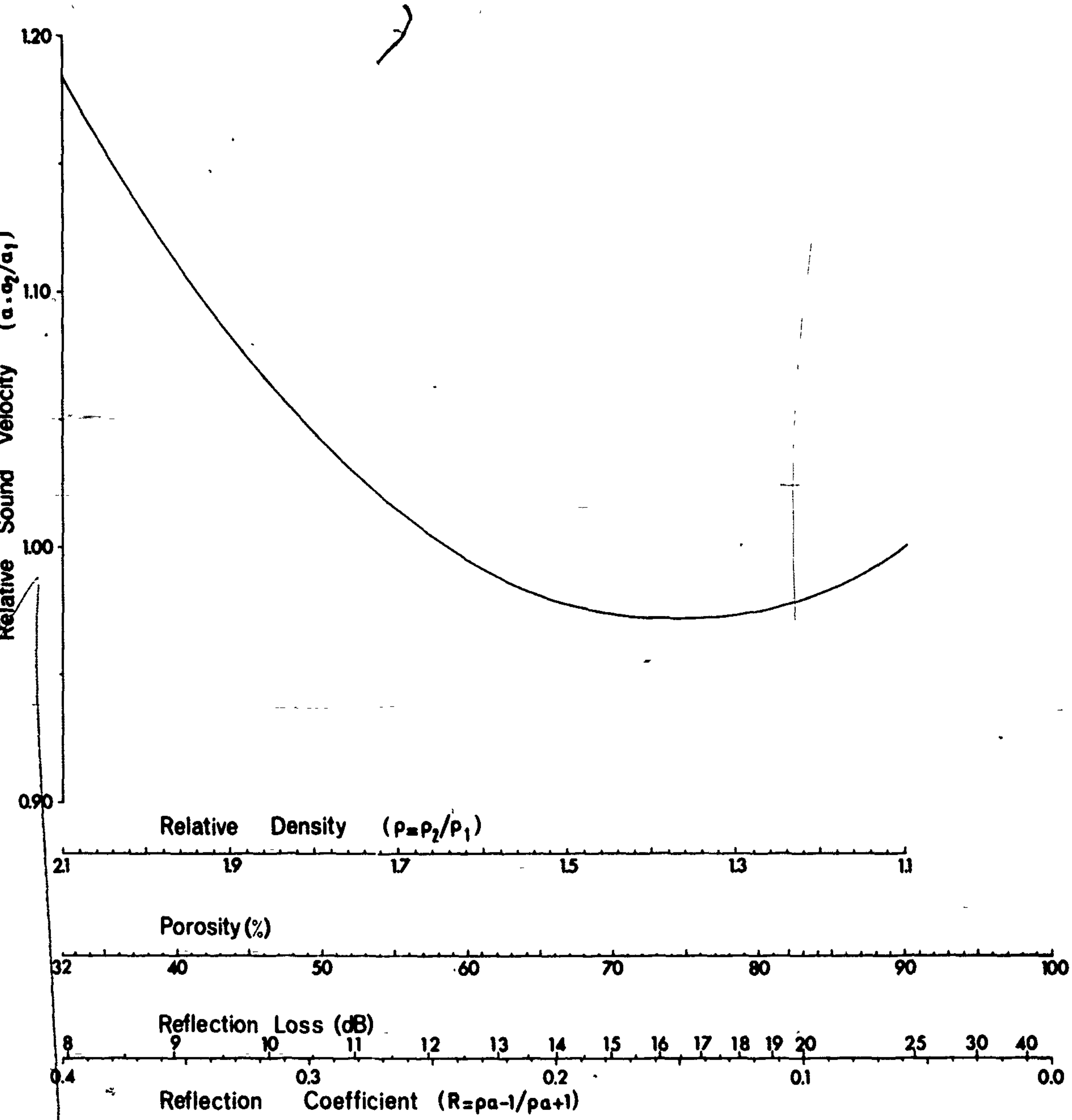



FIG. 12 RELATIONSHIP BETWEEN RELATIVE SOUND-VELOCITY AND THE REFLECTION COEFFICIENT, THE POROSITY AND THE RELATIVE DENSITY.

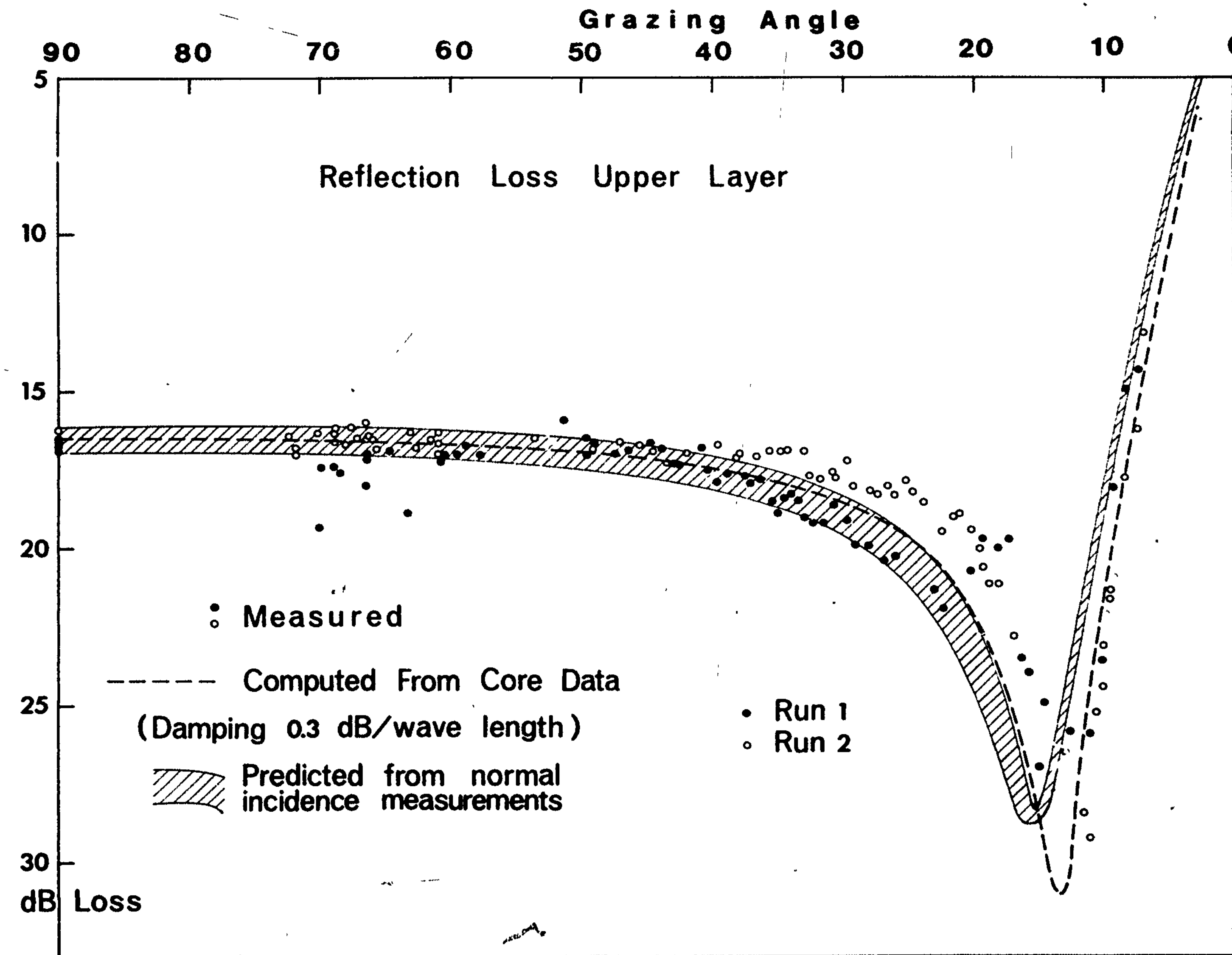



FIG. 13 MEASURED AND COMPUTED LOSSES AT DIFFERENT ANGLES OF INCIDENCE

## CONCLUSION

a. It has been demonstrated that, by compiling sufficient data from different oceans and different physiographic regions, it is possible to derive a statistical relationship between the properties affecting bottom reflection.

b. The porosity of the marine sediments stands out as the most important parameter causing variations in compressional sound velocity, density, and Rayleigh reflection coefficient.

c. If the reflection loss at normal incidence is known then by using the statistical relationships it is possible to predict the physical properties of the bottom sediments and extrapolate the losses for lower grazing angles.

## REFERENCES


1. Texas Instruments Inc. U.S. Naval Oceanographic Office Marine Geophysical Survey Program, 1965-1967, North Atlantic Ocean, Norwegian Sea and Mediterranean Sea. Dallas, Texas. 1967-69. (U.S. Naval Oceanographic Office. SP-95)
   Area 1, Vols. 5 & 6 — Area 5, Vol. 6
   Area 2, Vols. 5 & 6 — Area 6, Vol. 5
   Area 3, Vols. 5 & 6 — Area 7/4, Vols. 5 & 6

2. Alpine Geophysical Associates, Inc. U.S. Naval Oceanographic Office Marine Geophysical Survey Program, 1965-1967, Western North Atlantic and Eastern and Central North Pacific Oceans. Norwood, N.J. 1966-68. (U.S. Naval Oceanographic Office. SP-96)
   Area 1, Vols. 8 & 8B — Area SF, Vol. 8
   Area 2, Vol. 8 — Area HH, Vol. 4
   Area 5, Vol. 8

3. A. Kermabon, C. Gehin & P. Blavier, "Numerical Results of the Analysis of Sea-Bottom Cores (Naples & Ajaccio Zones)", SACLANTCEN Special Report M-46, July 1969, NATO UNCLASSIFIED.

4. C. Gehin & P. Blavier, "Numerical Results of the Analysis of Sea-Bottom Cores (Alboran Sea)", SACLANTCEN Special Report M-52, July 1969, NATO UNCLASSIFIED.

5. D.M. McCann, "Acoustic Properties of North Atlantic Cores", Vol. 2 Menai Bridge, University College of North Wales, Marine Science Laboratories, 1968.

6. E.L. Hamilton, "Sediment Sound Velocity Measurements made in situ from Bathyscaphe Trieste. J. Geophys. Res., Vol. 68, 1963, pp. 5991-98.

7. E.L. Hamilton, G. Shumway, H.W. Menard & C.J. Shipek, "Acoustic and Other Physical Properties of Shallow-Water Sediments off San Diego", J. Acoust. Soc. Am., 1956, pp. 1-15.

8. A.F. Richards, "Investigations of Deep-Sea Sediment Cores", P. 2: Mass Physical Properties. U.S. Navy Hydrographic Office, Technical Report No. 106, 1962.

9. G. Shumway, "Sound Speed and Absorption Studies of Marine Sediments by a Resonance Method", P. 1. Geophysics, Vol. 25, 1960, pp. 451-67.

10. L.R. Breslau, "The Normally-Incident Reflectivity of the Sea Floor at 12 kc and its Correlation with Physical and Geological Properties of Naturally-occurring Sediments", 1967, Woods Hole Oceanographic Institution, Ref. 67-16.

11. L.R. Breslau & H. Edgerton, "The Sub-bottom Structure of the Gulf of La Spezia". SACLANTCEN Technical Report No. 129, December 1968, NATO UNCLASSIFIED.

12. C. Gehin, SACLANTCEN, Private Communication.

13. J.J. Gallagher & V.A. Nacci, "Investigations of Sediment Properties in Sonar Bottom Reflectivity Studies", U.S. Navy Underwater Sound Laboratory. Report, 944. UNCLASSIFIED.

14. G.H. Sutton, H. Berckhemer & J.E. Nafe, "Physical Analysis of Deep-sea Sediments". Geophysics, Vol. 22, 1957, pp. 779-812.

15. J.E. Nafe & C.L. Drake, "Variation with Depth in Shallow and Deep Water Marine Sediments of Porosity, Density and the Velocities of Compressional and Shear Waves". Geophysics, Vol. 22, 1957, pp. 523-52. Also Lamont Geological Observatory. Contribution, No. 249.

16. B.C. Heezen, M. Tharp & M. Ewing, "The Floors of the Oceans, Vol. 1: The North Atlantic". New York, 1959. Geological Society of America, Special Paper, 65.

17. Washington, National Science Foundation, "Initial Reports of the Deep Sea Drilling Project". Vol. 1-2, 1969-70.

18. Turkish Navy Hydrographic Office, "Karadenizde Jeofizik Arastirmalar" DS 15, 1965.

19. W.B.F. Ryan & B.C. Heezen, "Ionian Sea Submarine Canyons and the 1908 Messina Turbidity Current". Geological Society of America Bulletin, Vol. 76, 1965, pp. 915-32. Also Lamont Geological Observatory. Contribution No. 831.

20. K.O. Emery, B.C. Heezen & T.D. Allan, "Bathymetry of the Eastern Mediterranean Sea". SACLANTCEN Technical Memorandum No. 129, January 1967, NATO UNCLASSIFIED. Deep Sea Research, Vol. 13, 1966, pp. 173-92.

21. A. Dahme, "Some Depth Profiles in the Ligurian Sea", SACLANTCEN Technical Memorandum No. 48, December 1962, NATO UNCLASSIFIED.

22. F. Giorgetti & F. Mosetti, "General Morphology of the Adriatic Sea". Bolletino di Geofisica, Vol. 11, 1969, pp. 49-56.

23. G. Dietrich & J. Ulrich, "Atlas zur Ozeanographie". Mannheim, Bibliographisches Institut 1968.

24. J.B. Hersey, "Sedimentary Basins of the Mediterranean Sea" in "Submarine Geology and Geophysics" ed. by W.F. Whithard and R. Bradshaw. London, Butterworths, 1965 (Colston papers, Vol. 17), pp. 75-91.

25. F.P. Shepard, "Submarine Geology", 2nd ed. New York, Harper & Row, 1963.

26. H.W. Menard, S.M. Smith & R.M. Pratt, "The Rhone Deep-sea Fan", in "Submarine Geology and Geophysics" ed. by W.F. Whithard and R. Bradshaw. London, Butterworths, 1965 (Colston papers, Vol. 17), pp. 271-85.

27. J.W.S. Rayleigh, "The Theory of Sound". Dover Publications, New York, N.Y., Vol. 2, 1945.

28. A.B. Wood, "A Textbook of Sound". G. Bell and Sons, London, 3rd rev. ed. 1955, repr. 1964.

29. R.J. Urick, "A Sound Velocity Method for Determining the Compressibility of Finely Divided Substances". Journal Applied Physics, Vol. 18, 1947, pp. 983-87.

30. G. Shumway, "Sound Speed and Absorption Studies of Marine Sediments by a Resonance Method". P. 2. Geophysics, Vol. 25, 1960, pp. 659-82.

31. M.R.J. Wyllie, G.H.F. Gardner & A.R. Gregory, "Studies of Elastic Wave Attenuation in Porous Media". Geophysics, Vol. 27, 1962, pp. 569-89.

32. O.F. Hastrup, "The Reflectivity of the Top Layer in the Naples and Ajaccio Abyssal Plains". SACLANTCEN Technical Report No. 118, July 1968, NATO UNCLASSIFIED.

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| NAMILCOM | 2 |
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| SACEUR | 3 |
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| SACLANTREPEUR | 1 |
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| CINCWESTLANT | 1 |
| CINCEASTLANT | 1 |
| COMMAIREASTLANT | 1 |
| COMCANLANT | 1 |
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| COMEDCENT | 1 |
| COMSUBACLANT | 1 |
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| NLR Belgium | 1 |
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